Effects Of Sediment Microfabric on Benthic Optical Properties

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LONG-TERM GOAL

My long term goal is to examine how inorganic factors, such as differences in sediment character or packing, contribute to the reflectance, scattering, and fluoresence of incident light at the seabed in coastal environments. Of particular interest is the degree to which the water column light field is sensitive to inorganic changes in bottom type, and whether such changes can be described in simple mathematical models. Ultimately, my intention is to apply this work to the identification of seabed sediment characteristics utilizing remote sensing platforms, such as hyperspectral satellite and airborne imagery.

OBJECTIVES

The Year 3-5 CoBOP proposal for my funding outlined four hypotheses to test that form the heart of my CoBOP objectives. They are 1) that the microfabric of grains at the sediment surface and to a depth of light penetration (~5 mm in well-sorted sands) has a strong impact on sediment reflectance and the in-sediment light field; 2) that the fluorescence of carbonate mineral grains is virtually universal in carbonate settings, and therefore, has a significant effect on sediment reflectance, while carbonate and other biogenic grains compose a smaller percentage of siliciclastic sediments and has an inconsequential impact on the overall benthic light signal; 3) that siliciclastic mineral fluorescence is present in 5-10% of the mineral grains in siliciclastic environments and is a useful tool for sediment provenance; and 4) that inorganic variations in grain size and composition are the first-order control on sediment reflectance and the in-sediment light field in bare sediments not covered by a significant algal mat or biofilm. In the latter areas, organic absorbance at specific wavelengths is a major contributor.

APPROACH

My approach for solving the four objectives outlined above has been two-fold. Objectives #1 and #4 have involved the development of a fiber-optic microprobe system that can be used to profile scalar irradiance from the sediment surface to the limit of light penetration in undisturbed sediment cores. The success of this methodology has yielded spectral information (350-800 nm) from a variety of sediment settings. Core preservation methodologies have permitted preservation of original fabric for later impregnation and thin-sectioning to give quantitative information about inorganic properties of the sediments that are inducing changes in the light field. The methodology has also allowed for manipulation experiments to determine the relative impact of inorganic and organic sediment parameters. Objectives #2 and #3 have been approached by using a microspectrofluorometer build into an epi-fluorescence microscope to generate and measure the spectral properties of sediments on a

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single-grain level. This has been supplemented by the use of a Fluoromax spectrophotometer to examine whole-sediment properties.

WORK COMPLETED

Field studies have been completed in league with other CoBOP PI's to Lee Stocking Island (LSI), Bahamas and Monterey Bay. LSI studies were conducted in May 1998, January 1999, and May, 1999. Monterey studies were conducted in April 1998, October 1998, and April 1999. Fiber-optic microprobe in-sediment light profiles have now been collected at all major sub-environments at each CoBOP field site in the two areas. Seasonal differences have also been measured at several of the key localities. All the 1998 and January 1999 profile data has been submitted to the web-accessible CoBOP database.

Core material has been impregnated and over 100 thin-sections generated for cores analyzed by fiber-optic microprobe. Computer imaging software is being used to reduce information from each thin-section about downcore variations in porosity, grain size, shape factors, etc. All software results and the latest field results will be transmitted to the CoBOP website by year's end. Representative grain samples have also been collected and isolated for fluorescence studies at each of the major sub-environments at Monterey and LSI. Samples were also collected from representative beaches and nearby coastal environments to track source functions for the fluorescent particles. A suite of particle end members was analyzed by Fluoromax spectrofluorometer to determine the range of fluorescence observable at LSI. Detailed studies of the site grain fluorescence are ready to begin before year's end with the upgrade of the epi-fluorescence microscope to do rapid spectral response fluorescence imaging with the addition of an Ocean Optics S2000 spectrophotometer.

RESULTS

Our results to date from the fiber-optic microprobe work show that there is considerable variation in the downcore light field between sites (Fig. 1). Light field variations are observed that correspond to changes in the mineralogy or packing layers downcore. However, our studies of standard seived mixtures (Fig. 2) have shown that, within the limited grain size and shape variations present in the LSI and Monterey sites, the downcore light signal is relatively insensitive to changes in grain size and shape.

At many sites, the biological effects of absorbance by CDOM, biofilms, and benthic organisms (diatoms, etc.) overwhelm variations induced by inorganic differences in the sediment. This can be seen both in the increased porosity induced by surface mats and films (Fig. 1) and in the resulting profiles in cores where the biological component has been removed (Fig. 3) for comparison with the pre-treated light field.

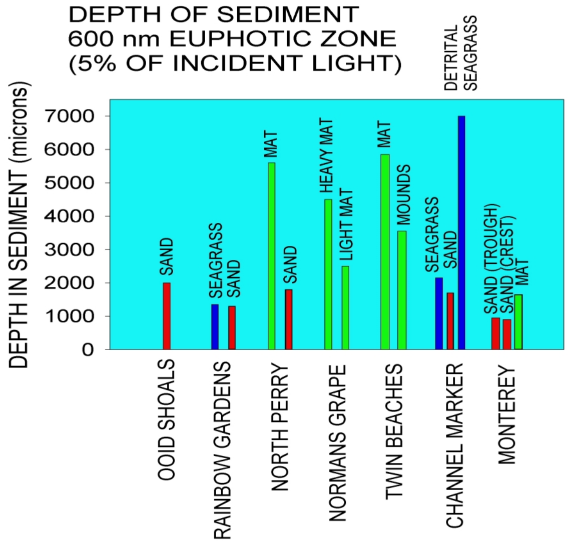

Figure 1. Summary of depth of light penetration (5% of incident) fiber-optic microprobe measurements for all the major field sites at LSI and Monterey Bay in 1998-1999 at a representative wavelength (600 nm). Data shows that light penetration at sites where the sediment is covered by an observable biogenic mat (diatoms, etc.) is 2-3X bare sediment (inside or outside of seagrass cover) of the same type. This is attributed to the effects of increased porosity (spacing between grains) caused by the growth of organisms. Note also the lower penetration in the siliclastic sands at Monterey relative to LSI carbonates, attributable to the higher albedo of the carbonate (increased internal scattering in the sediment).

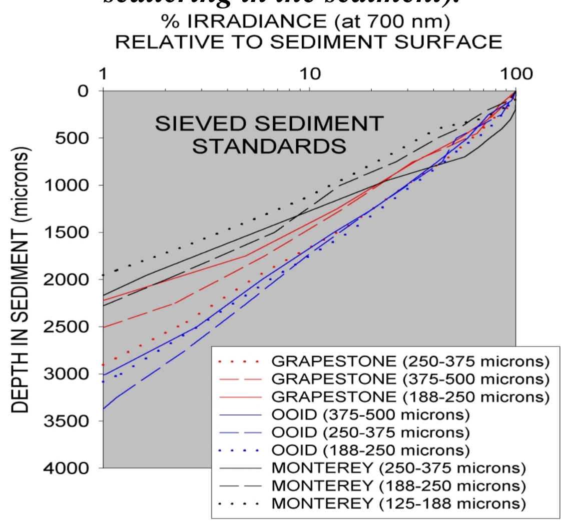

Figure 2. Downcore fiber-optic light profiles of sieved sediment standards collected from two sites at LSI and the Monterey site plotted as a natural log relative to the light measured at the sediment surface (at 700 nm). These cores were mixed to remove inorganic fabric differences and bleached to remove organic components (CDOM, biofilms, etc.). Profiles show an exponential decay in light penetration. This information provides a modeling standard that allows comparison of fiber-optic measurements from undisturbed cores to examine inorganic and organic perturbations from this mean value. Given that seabed reflectance measurements correlate strongly with depth of penetration into the sediment at a given wavelength, ultimately this data can be used to deconvolve reflectance data to reveal information about the microfabric below the seafloor. This idea will be tested in the 2000 field experiments.

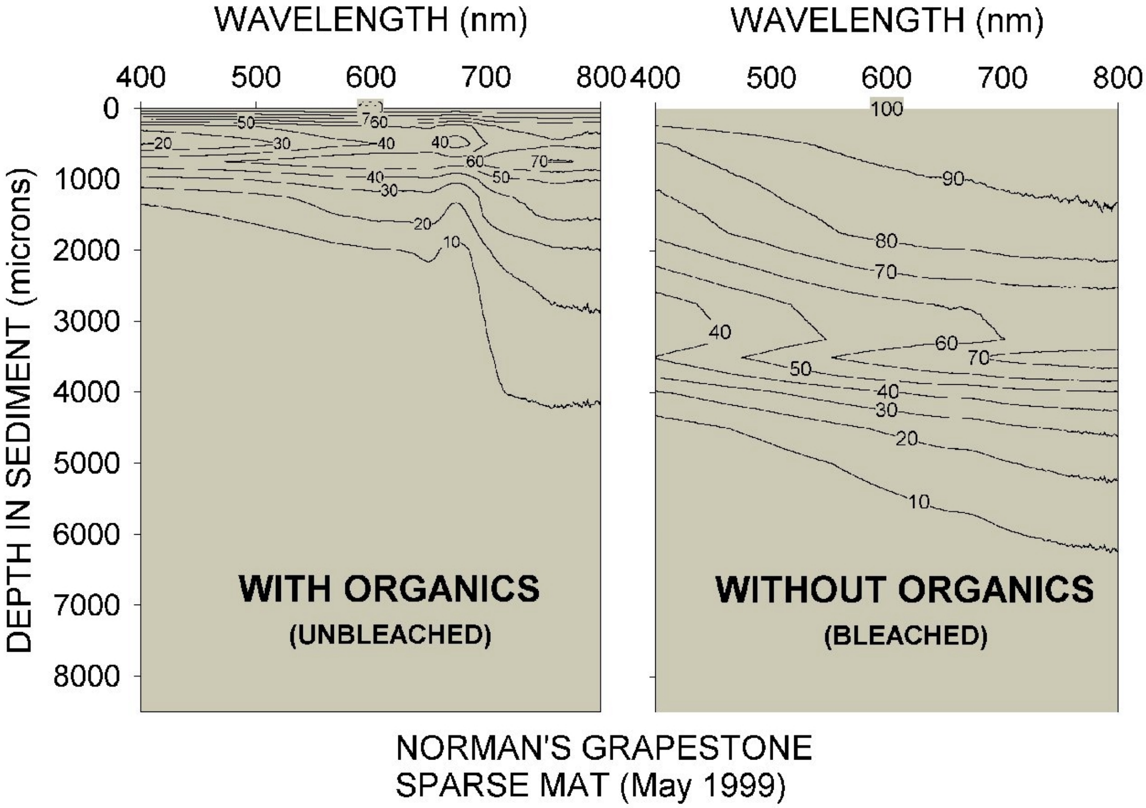

Figure 3. Downcore spectral fiber-optic measurements of light penetration in an undisturbed sediment from the Norman's Grapestone site at LSI before and after bleaching to remove organic components. Plot contours represent % of incident light relative to the surface value. In the unbleached run, note the strong chlorophyll absorbance at 670 nm and the overall shallow penetration (2-4 mm) of light. After removal of the organic components penetration increases to 5-6 mm suggesting organic components are absorbing and/or reflecting a significant percentage of the incident irradiance.

IMPACT/APPLICATION

Our fiber-optic microprobe work on sediment light fields is the first done on undisturbed marine sediments. It has shown that light fields can be easily modeled as a exponential decay downcore. This will permit variations induced by inorganic or organic structures in the sediment to be readily identifiable. Future field work will be integrated with measures of sediment reflectance to determine to what degree the reflectance signal represents light that has penetrated the seabed and returned to the surface. The impact of this work raises the possibility of identifying sub-seafloor features solely from

the reflectance spectra, given that our microprobe work has also shown that depth of penetration of light is predictable dependent on wavelength (longer wavelengths penetrate further).

The grain fluorescence work to date has shown that it is the source of the apparent green background light visible in scans with laser line scanning systems at LSI. In siliciclastic sediment (Monterey), the mineral- and site-specific nature of fluorescence holds great promise as an indicator of sediment transport vectors in sandy sediments.

TRANSITIONS

I am investigating the use of fluorescent siliciclastic sediment grains as a provenance tracer working with Brian Edwards and Steve Ettriem (USGS Menlo Park) in Monterey Bay, CA. We hope to establish the validity of this technique and to use it as a tool to determine sediment transport vectors as a means of tracing the dispersal of contaminated sediments in a USGS study of the the Monterey Bay and Gulf of the Farallons National Marine Sanctuary.

RELATED PROJECTS

1 – David Burdige (ODU) and I are beginning a series of experiments on Lee Stocking Island carbonate grains to determine the organic (humic) substances that are present in the crystalline structure and whether they are the origin of the widespread broadband and week fluorescence noted in CoBOP studies of the area.

2 – I am working with the CoBOP sediment group (P. Reid, U. Miami, L. Brand, U. Miami, R. Wheatcroft (Oregon State), David Burdige (ODU), Fred Dobbs (ODU) and Alan Decho (U. South Carolina) in coordinating our sediment sampling of inorganic and organic parameters at the LSI and Monterey sites to determine the relative importance of our individual measurements in the benthic light signal. These measurements are being interfaced with reflectance measurements at the sites being made by C. Mazel (PSICORP), P. Reid (U. Miami), and Ken Voss (U. Miami).

3 – I am interacting with C. Mazel (PSICORP) in an effort to relate my measurements of in sediment light profiles to spectral reflectance data at the LSI sites to devise methodologies for deconvolving reflectance data to give information about the biological or inorganic changes occurring below the sediment surface.

PUBLICATIONS

Taylor, B.B. and Allison, M.A., 2000. Characterization of the In-Sediment Light Field of Sandy Coastal Environments. EOS, Transactions of the American Geophysical Union, abstract volume in preparation for February meeting.

Allison, M.A. and Taylor, B.B., in prep. The Use of Grain Fluorescence as a Provenance Tracer of Transport Vectors in Marine Sands. American Society of Limnology and Oceanography Annual Meeting, June 2000.